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INTER-OCEANIC CANAL PROJECTS.*

DISCUSSIONS

By J. DIRKS, A. COUVREUX *fils*, ASHBEL WELCH, WILLIAM E. MERRILL, CHARLES MACDONALD and T. C. CLARKE.

Discussion by JUSTIN DIRKS.

Some criticisms have been made on the prices for various kinds of work on the Panama Canal, which were adopted by the Technical Committee of the Paris Congress, of which I had the honor to be Chairman.

These prices are as follows :

		Francs per cub. metre.	Cents per cub. yd.
Earth	For dry excavation	2.50	38.5
Rock of mean hardness	" "	7.	108.
Hard rock	" "	12.	185.
For excavation, including pumping, rock of any kind		18.	277.
For dredging and excavation under water, mud and alluvial soil		2.50	38.
Dredging hard soil		12.	185.
Removal of rock		35.	539.

*Inter-Oceanic Canal Projects, Vol. VIII, p. 311 (November, 1879). Vol. IX, p. 1 (January, 1880). Vol. IX, p. 47 (February, 1880). Vol. IX, p. 87 (March, 1880).

It has been stated that these prices are less than they should be. I beg to ask your kind attention to a statement of the basis of the estimates of prices.

The price of 38.5 cents per cubic yard for excavation or dredging of earth and alluvial soil, was fixed in the first place by Messrs. Wyse, Reclus and Sosa. It was submitted to practical men: First, To Mr. T. A. Ros, one of the largest contractors in the Netherlands, who said that the removal of earth, either by excavation or dredging, ought never to cost 38 cents per cubic yard, even if all the machinery and workmen had to be brought from abroad.

In fact, Mr. Ros stated to me, on another occasion, that he would be ready at any time to make near Utrecht a cutting of six millions of cubic metres (say 7 800 000 cubic yards), including a maximum haul of 2 000 metres to a spoil bank at 0.70 francs per cubic metre, or about 11 cents per cubic yard.

A smaller quantity of soft mud to be dredged, transported by boats, discharged into the water, dredged again and pumped over into a secluded area of water, was contracted for between myself and Mr. T. Van de Velde, at the price of 18 cents per cubic yard.

Mr. Dauzats, who sailed this morning for Havre, states that at the Suez Canal the cost of excavation or dredging of such material never reached 15½ cents per cubic yard.

There is such an enormous difference between 11, 15.5, or even 18 cents per cubic yard, and the adopted price of 38.5 cents, that the last named seems as if it ought to cover all contingencies.

Mr. Dauzats stated to me that Messrs. Lull and Menocal were satisfied to put the prices for the Panama Canal plan at 35 cents for earth and 40 cents for soft mud.

For excavation of rock of mean hardness, where pumping is not required, the price of 7 francs per cubic metre ($1.08 per cubic yard), was fixed by Messrs. Wyse, Reclus and Sosa, and was approved by M. Couvreux *pere*, the well known French contractor, in the following terms: "Your prices for *any* rock to be excavated and removed, without pumping, will be very remunerative. It seems to me, upon examination, that they might even be reduced, in view of the methods which will be employed in excavation."

This remark was intended to apply also to the price of 10 francs per cubic metre ($1.54 per cubic yard), for the excavation of hard rock where

no pumping was required, as proposed by Messrs. Wyse, Reclus and Sosa, and it therefore covers the case of the price of 12 francs per cubic metre ($1.85 per cubic yard) fixed by the Paris Congress.

Mr. Ros states that basalt from the Rhine and limestone from Tournay, in Belgium, cost less than $1.85 per cubic yard, even including transportation by water for a distance of 200 kilos (125 miles).

Mr. Dauzats informs me that the prices set by Messrs. Lull and Menocal in their estimates of a Panama canal, for all kinds of rock above water, were only $1.25 to $1.50 per cubic yard, or 35 to 60 cents less than the Paris Congress prices.

For excavation of rock where pumping is required, the price of 18 francs per cubic metre ($2.77 per cubic yard) was obtained simply by adding 6 francs per cubic metre (92 cents per cubic yard), to the price for dry excavation.

There is room for difference of opinion as to the sufficiency of this addition to cover unforseen contingencies. I would say on this subject—First, that a part and possibly a large portion of the rock to be excavated where pumping will be required, will prove to be of mean hardness; but the price for all such is fixed at 92 cents more than for hard rock.

Secondly, that additional price of 92 cents per cubic yard, for pumping only, seems rather high. I never experienced pumping as costly as this, even in loose sand. There is a fair chance that the pumping at Panama will not prove more expensive than that at the recent excavations near Hell Gate, where, as I was informed by General Newton himself, the maximum amount of water encountered at a depth of 26 feet below ordinary low-water level was 200 gallons per minute.

The prices of the Paris Congress were adopted, therefore, after long discussion, and with the full approval of your distinguished countrymen Colonel Totten and General Wright, as *thoroughly* high figures, in order to ensure full security.

I beg to observe further, that the Paris Congress only approved these prices. They were established by the first sub-commission of the Congress, composed of the following well known, thoroughly practical engineers and contractors, namely:

M. Cotard, late Engineer of the Suez Canal contractors.

M. Couvreux *pere*, contractor for the Danube works, the canal be-

tween Ghent and Ter Neuze, and the harbor works at Antwerp, and late Contractor on the Suez Canal.

M. Lavalley, Chief Engineer of the Ponts et Chaussèes and late General Contractor for the Suez Canal Works.

M. de Lepinay, Chief Engineer of the Ponts et Chaussées, who designed and executed several works in the Mexican Republic.

M. Ruelle, Chief Engineer of the Ponts et Chaussées and Director of Construction of the Paris, Lyons and Mediterranean Railway.

M. de Garay, Civil Engineer, General Director of the Desague works of the Valley of Mexico.

M. Louis Favre, contractor for the St. Gothard Tunnel, the completion of which has just been telegraphed from Europe. [Most unhappily, this clever and self-made man died a few months ago, shortly after the closing of the Paris Congress.]

The above names speak for themselves. It seems unnecessary, therefore, to dwell longer on the question of prices, as from what has been said it is plain that the last Committee wished to exclude any figures which might afterwards prove too low. So fully satisfied were they that this object had been accomplished, that they did not hesitate to reduce the allowance for contingencies to the usual ratio of 10 per cent., which in this case amounted to 76 millions of francs, or about 15 millions of dollars.

Though my professional colleagues of M. de Lesseps' Staff, left this city this morning, I am prepared of course to discuss any remarks that may be deemed advisable by members of this Society.

[In reply to questions asked by several of the members present at the meeting, and also to questions sent by letter by A. G. Menocal, Member of the Society, Mr. Dirks made the following answers :]

What is the nature of the soil or formation at the site of the proposed dam across the River Chagres ?

Mr. J. Dirks.—The soil at the site of the proposed dam across the River Chagres is a stiff clay. There seems to be no sand in it at all. Most of the clay in Holland has considerable admixture of sand, but this seems to be purely clay. It is very hard, and I consider that it will afford a sufficient foundation for the dam without excavating to the rock, some 20 feet below.

Have a sufficient number of borings been taken to ascertain with

certainty the nature and quality of the rock on which the foundations of the dam will rest? If so, what is the character of the rock?

Mr. J. Dirks.—The rock at the site proposed for the dam is hard rock, and in my opinion sufficiently strong to sustain the dam, and such stone as may be excavated can be used in the construction of the dam. I regret that Mr. Boutan, the engineer who made the special examinations as to these points, has been compelled to return this morning to France, and that therefore the information given you this evening is not as full as it would be if he were present.

A number of borings were made to the rock, at the site of the proposed dam, as stated in the report of the technical commission.

Vice-President Chanute.—I desire to say that M. De Lesseps promises to transmit to this Society a full report of the results of the late technical examination of the line proposed for the Panama Canal. But as this involves the collation of the records and field notes of all the parties engaged upon the surveys, it will be some time before it will be possible to furnish the report and send it to us.

A Member.—Has a detailed survey been made of the water-shed of the Chagres above the site of the dam?

Mr. J. Dirks.—The examination of the water-shed of the Chagres was made by M. Dauzats, the Engineer of the Suez Canal, and the dimensions of the proposed dam were determined by him in consultation with the other members of the technical commission. A plan has been completed on a very large scale of the part to be covered with water, upon the completion of the dam, and its cubic contents, which are estimated at 1 000 000 000 cubic metres, have been calculated.

By what means was the last flood of the Chagres measured at its different stages of rise and fall, so as to determine accurately the amount of water passing through a given section?

Mr. J. Dirks.—The information as to the flood of the River Chagres was collated by Col. Totten from data given by officials of the Panama Railroad, which those officials state were very carefully secured. Col. Totten prepared a very full and very interesting memoir, in which he showed in detail the flow at various points, and calculated the total quantity of water, which proved, if I remember right, somewhat less than the cubical contents of the proposed impounding reservoir back of the dam at Gamboa.

What is the maximum carrying capacity of the proposed artificial channel from the reservoir to the sea?

Mr. J. Dirks.—The capacity of the proposed artificial channel from the reservoir to the sea is two hundred cubic meters per second. The time required therefore to empty the impounding reservoir would be, *calculating* 1 000 000 000 cubic metres, divided by 200—which gives it to us in seconds—about 58 days, provided no more rain fell in the meantime. The management of the flow, whether into the main canal or the subsidiary channel, will doubtless be properly arranged by the Engineers who may be engaged upon that service.

How is the Obispo river going to be disposed of? Will it be made to discharge into the basin or directly into the new channel?

Mr. J. Dirks.—The Obispo is but a small stream. There would be no great harm in allowing it to flow into the canal, but if upon further investigation this is thought objectionable, it can be swung across the canal on a draw-bridge, and allowed to flow through a trough when no vessels are passing, being kept back at other times by a sluice-gate.

What is the estimated time required for building the dams and the artificial channels?

Mr. J. Dirks.—The time estimated as requisite for the completion of all the works, is 8 years; if driven with vigor it can be done in that time.

By what methods is it proposed to dispose of the waters of the Chagres and other streams during the construction of the dam and new channels, so that the work on the canal can be proceded with from Matachin to Aspinwall?

Mr. J. Dirks.—It will not be hard to manage the Chagres during the progress of the work. In Holland we generally allow the waters to rise in a reservoir behind a dam at the same time that we build it, and it will probably be so managed at Panama, the dam being begun in the dry season and raised uniformly over its entire length, so that the water shall raise at the same time, any surplus, or apprehended surplus in time of rains, being let off by the artificial channel.

Have any provisions been made to keep the canal free from the Rio Grande? If so, what do they consist of, and under what heading do they appear in the estimate?

Mr. J. Dirks.—The Rio Grande is mainly a tide-water river; its watershed and drainage is small, and but little water except that from the

tide comes into it; cut that off, and it will almost disappear. We might turn its flood-water into the canals without inconvenience.

By what method is it proposed to drain the country on the south side of the canal, from the dividing ridge to the River Trinidad, a distance of not less than 25 miles by the line to the canal?

MR. J. DIRKS.—There are no streams of magnitude in the country referred to, and such drainage as may be necessary can easily be provided for.

How many tide-locks are proposed? and can ships approach and leave the canal through the tide-lock at all states of the tide?

MR. J. DIRKS.—One tide-lock is proposed at the Pacific end of the canal, and it is intended to place its bottom at such elevation with reference to the tides as will enable vessels to enter it at any time.

What is the estimated time for a ship to pass the tide-lock?

MR. J. DIRKS.—One hour has been allowed for passing the tide-lock.

Can the tide-lock, in your opinion, be built for the estimated sum of 12 000 000 francs?

MR. J. DIRKS.—I am not a contractor, but if I were, I think I would be quite ready to undertake to build it for that sum. From the experience of the cost of the locks of the North Sea Canal, I should say that the estimate was safe.

Would it not be fair to add to the estimates made by the Technical Commission, and based on the prices fixed by the Congress at Paris, the commissions to bankers, interest during construction, indemnification to the Panama Railroad and to the Company owning the concession from the Colombian Government, and a per centage for contingencies, before a promise is made as to probable profit on capital?

MR. J. DIRKS.—The Technical Commission was requested simply to make estimates of the probable cost of the work; it was not requested to, and consequently did not, consider the subjects of commissions to bankers, etc. There is added for contingencies, as will be seen by reference to the report of the Commission, the usual ten per cent., or 76 000 000 francs to the total estimated cost.

What is the time estimated as required to complete the proposed canal?

MR. J. DIRKS.—Eight years.

VICE-PRESIDENT CHANUTE.—Mr. A. Couvreux *fils*, partner of one of the largest engineer contracting firms in Europe, which executed much

of the works on the Suez Canal, has kindly offered to give us an account of Inter-Oceanic Canal enterprise since the Paris Congress, and of the late expedition to Panama, of which he formed a part, having subsequently come to the United States with M. De Lesseps. He will make his address in French, and I will translate it into English as he proceeds, to the best of my ability.

Discussion by A. COUVREUX *fils*.

In calling the Paris Congress, M. De Lesseps addressed about 300 invitations to distinguished engineers, and to the persons who were thought to be best fitted to take part in its deliberations.

Of these, about 100 attended in May last, and among them, Admiral Ammen, M. Menocal, and several other gentlemen well and favorably known in this country.

After a full and free discussion in that Congress, the Panama route was decided upon, and M. de Lesseps was urged by his friends to take the direction of the enterprise. This he readily consented to do, and he took steps to organize a company to execute the works.

A "Compagnie Civile," or a syndicate as you call it in this country, had already been formed under the presidency of General Turr, and had obtained through its representative, Lieut. Com. N. B. Wyse, a concession or charter from the Colombian Government conferring certain rights and privileges for the building of a canal across the Isthmus of Panama, as well as proposals for a contract for the purchase of the Panama Railroad from its owners.

After the close of the Congress, this syndicate agreed to transfer all its rights to M. De Lesseps, including its charter, concession of lands, project of contract with the railroad, etc. Thus M. De Lesseps became the sole proprietor of the right and charter to build a canal across the Isthmus of Panama.

The numerous friends of M. De Lesseps gathered around him, and made up a sum of $400,000, which they placed at his disposal to defray the expenses of verifying the surveys, and organizing the Canal Company. In consequence thereof, he was enabled to make the deposit of $150,000, which the concession from the Colombian Government required should be paid into its hands, in silver, as security for the undertaking of the works, and to secure certain rights.

He then opened subscription books, and offered to the public an

opportunity to take the stock of the company which was to complete the canal. He failed, however, in obtaining the requisite amount of capital.

This took place so soon after the closing of the Congress, that the American newspapers giving an account of the reports of the American Delegates, and attacking the resolutions of the Paris Congress adopting the Panama route, had not arrived in Europe; but it was known by telegraph that serious opposition to the canal existed in the United States, and this threw a cloud over the enterprise, which, combined with opposition at home, was sufficient to defeat the subscription.

M. De Lesseps had entered into communication with the leading banking houses in France, as well as those of other parts of Europe. A practice has lately sprung up among bankers by which, instead of acting as agents upon a commission for the receipt of subscriptions, they buy large blocks of the stock of new companies on private terms, and then sell them to the public at an advanced price. Now, M. De Lesseps is opposed to this; he desires that each stockholder shall acquire his stock at par, instead of paying to bankers a profit of 20 to 30 per cent., and he refused the terms which were offered him. Whereupon all the papers interested in banking or controlled in one way or another by the bankers, began to make fierce attacks upon M. De Lesseps and his scheme, which they kept up day by day, and to which he never replied. Sometimes representatives of the less reputable of these sheets, called at the office of the Suez Canal, and showed articles already in type, favoring his project, which they offered to publish for a consideration. He refused such offers, whereupon an article favoring the Nicaragua route would generally come out of the other pocket, and an offer to suppress it be also refused. Moreover, there was no popular local interest to appeal to. When the Suez Canal was organized, it was expected largely to increase the Mediterranean commerce of France, and large subscriptions were obtained at Marseilles, and in the South of France; while in the case of the Panama Canal, the advantages were remote, and the work was in a foreign country, where it would be of equal advantage at least to other nations.

Thus the first attempt to organize the Panama Canal Company did not succeed, but nevertheless M. De Lesseps did not abandon his scheme. His views were wider. He applied to M. Dirks, and to other engineers, and asked them to join him in organizing an expedition to verify the surveys at Panama, and to come to the United States, and with their aid

he organized the "International Technical Commission," which took up the whole question as left by the Congress.

Meanwhile M. De Lesseps, who always seeks to obtain information from practical men, and to consult those who have been in the habit of carrying on great enterprises, had previously applied to our contracting firm*, and asked us to send a representative to examine the country and the climate at Panama. We sent M. Gaston Blanchet, one of our engineers, who arrived at Panama early in September, 1879, and he soon cabled us, from what he saw, that there was no material difficulty in the way of a sea-level canal, but that it would be necessary to make careful and complete surveys, to determine the plans to be adopted, and the character of the rock to be excavated.

Upon receipt of this despatch, M. De Lesseps sent out a mining engineer, M. Jegou, the same who conducted so successfully the borings in the Algerian "Chotts" in the expedition of Commander Roudaire. He took with him six sets of boring tools, so arranged that they could penetrate to a depth of 200 feet each, and Messrs. Duflos and Barbier to take charge of their working. He also took with him Messrs. Marolle Brothers, who are experienced levellers and surveyors, to aid in the work.

During the time that this party was organizing, M. Blanchet was sending from Panama reports by every mail to Paris, all of them uniformly favorable in character, as to the practicability of the canal, but about this time the cable broke, and M. Blanchet, receiving no advices or instructions from Paris, and not knowing that a party was about to sail, went back to France, in accordance with his original instructions.

Accordingly, when Messrs. Jégou, Duflos, Barbier and Marolle Brothers arrived at Aspinwall, M. Blanchet was no longer there, but they met M. Sosa, an eminent Colombian engineer, educated in the United States, and a very agreeable gentleman, who was thoroughly familiar with all the surveys made by Lieut. Wyse and others. He had pluckily gone from Panama to Aspinwall during the great flood in November last, most of the way in a canoe, and had measured, on his way down, the speed of the current and the height reached at several points. His measurements and deductions are somewhat at variance with the conclusions of Col. Totten, as presented by the latter to the Technical Commission.

*Couvreux, Hersent & Co., contractors for the Suez Canal, the Canal from Gand to Terneuzen, the Port of Antwerp, the works on the Danube, etc., etc.

Acting upon M. Sosa's suggestions, M. Jégou and the other gentlemen whose names have been mentioned, took up their positions at various points on the Isthmus, and began boring, operations which are not yet completed.

M. Blanchet fortunately arrived in France before the sailing of M. De Lesseps, and he immediately returned to Panama with him and the Technical Commission, being convinced that they could only bring back from America a favorable report. His perfect state of health afforded convincing proof that Panama could not be the charnel house for Europeans which it has generally been represented to be.

Our expedition sailed from St. Nazaire on the 8th of December, 1879, in the steamer Lafayette. During the ocean trip the Technical Commission held several sessions. At the first meeting M. De Lesseps presented a programme of operations, consisting of the eight questions which are answered in the report of the Commission.

M. De Lesseps stated that it was not his object to ascertain exactly what would be the cost of the canal, including the expenses of management, interest and discounts, purchase of the railroad and other properties, etc., etc.; but that he desired the Commission to confine itself to the technical portion of the subject, and to inform him whether the figures presented by Lieut. Wyse, his longitudinal and cross sections, and computation of cubical quantities, were correct; and whether, in the judgment of the Commission, the works could be executed at the prices fixed by the Paris Congress. He asked for a report at the end of January.

The Commission was somewhat dismayed at the amount of work that this involved. Whereupon it was resolved that all should work, each accomplishing as much as he could. M. Dirks kindly consented to calculate personally the cross sections, in addition to taking charge as the head of all the surveying parties. He worked night and day, especially towards the last, as he wanted to be certain of the correctness of all the figures. The work for the surveys of the 45 miles of canal was divided up among five parties.

M. Pierre Marolle was placed under my orders to take charge of the surveys, from kilometer 73, the terminus at Panama, to kilometer 55, at the head of the Rio Grande, and explored the valley of this stream between those points. We had with us two aids or interpreters belonging to the country, and fifteen negro laborers.

The second party was directed by M. Jégou. He surveyed the

Culebra ridge or great summit cut, from kilometer 55 to kilometer 40, and was assisted by two local aids or interpreters, and fifteen negroes.

The third party was under the charge of M. Dauzats, who, with Messrs. Ortega and Ossa, and the required number of aids and laborers, took special charge of the surveys for the projected dam across the Chagres River at Gamboa, and the valley to be flooded above it by the dam.

The fourth party surveyed the location of the canal along the Valley of the Chagres, from kilometer 40 to kilometer 20. It was in charge of M. Sosa, who was assisted by M. Fontan, Engineer of the Ecole Centrale of Paris, two aids or interpreters, and fifteen or twenty negroes.

The fifth party took charge from the 20th kilometer to the Atlantic Ocean, in the lower valley of the Chagres. It was in charge of M. Albers, with Mr. Charles Marolle and the usual number of aids and laborers.

We arrived in Panama on the evening of the 31st December. The first three days were taken up in receptions and dinners. Nevertheless the mornings were employed in digesting—our instructions and organization. Each day a session of the Commission took place, M. Dirks presiding.

On Monday morning, the 4th of January, 1880, all the parties started for their work by the seven o'clock train.

And here we wish to express our thanks to the managers of the Panama Railroad Company, who at this and all other times, placed their line and trains at our disposal, in the most courteous and efficient manner.

Each party selected and established its headquarters at some point most convenient for carrying on its work.

In accordance with instructions previously received, every two or three days, the head of each party went to Panama, which was established as headquarters, to present a report of his progress, and write out the contents of his notebooks. Thus we managed to get 58 cross sections of the valleys. As soon as all the parties had returned to Panama, there was a full session of the Technical Commission.

At this M. Dirks exhibited a compendium of the information obtained by the different parties, and we made the calculations of heights, and computations of various quantities. This, however, took but a minor part of the time consumed; most of it was spent in discussion of the

plans and of the execution of the works, as well as the prices which should be estimated for them. It was thus, as M. Dirks has explained, by a comparison of views, and discussion of methods and prices, that the lump estimate of twenty millions of dollars for the dam across the Chagres was arrived at. This large estimate, so stated, should indicate to you that the various members of the Commission were by no means agreed as to the cost of the various detailed parts of such a dam. As for myself, I believe that further examinations will disclose that there are other locations where the projecting spurs of the mountains afford a better position for the dam, and where a less expensive structure can be substituted for the one estimated for.

At length the Technical Commission arrived at definite conclusions upon all the questions which had been put by M. De Lesseps, and on the 14th of February we had the satisfaction of signing the report and placing it in his hands.

Immediately thereafter most of the Technical Commission left Panama for the United States with M. De Lesseps, leaving instructions with M. Sosa and other gentlemen whose names have been mentioned, to complete some special surveys, and especially the borings.

This will require some little time, as the borings begun in November were not completed in February to the full depths required in order to obtain a full and clear geological section down to the bottom of the canal, of all the rocks of the entire Isthmus. All the records of these borings, as well as the samples obtained in them, and during the progress of the surveys, will be sent to M. Boutan in Paris, who has special charge of the geological branch of the examination, and who will make a full report thereon, so that intending contractors may be fully advised of the materials to be encountered.

It was upon the receipt of the report of the Technical Commission that M. De Lesseps drew up the circular addressed to American bankers, who may take charge of receiving subscriptions to the shares of the Inter-Oceanic Canal Company.

It has been asked why, when the Technical Commission reported the probable cost at $168 000 000, M. De Lesseps proposes to organize his company with a capital of only 120 millions of dollars.

In the first place, it is certain that material economies can be made in the execution of the works, from the estimates presented by the Commission, for it will be noticed that the prices given are materially higher than those adapted for the estimates of the Nicaragua project.

Moreover, it is very certain that if the 120 millions of dollars, which M. De Lesseps proposes to raise, are not sufficient to finish the canal, he can always put a mortgage upon it. Therefore it seems unwise to start with a larger sum than 120 millions, especially as interest will be lost on what is kept on hand, and it may not be necessary to spend the whole of it.

M. De Lesseps told me to express his regrets that he could not be present on this occasion, as he has to attend two meetings this evening. From the reception which, much to his gratification, he has received in New York, he has great confidence in the future success of his enterprise. For in point of fact whither is the discussion now leading—is it to the adoption of his project for a canal at Panama, or of the Nicaragua route? It does not seem to favor the latter, yet if its friends still have confidence in its merits, let them raise the capital and build the canal there.

At Panama three schemes are presented, a sea-level canal, a canal with locks, and a marine railway.

The marine railway proposes to transfer ships on cradles from one ocean to the other, but the author of the project does not state how many trips he can make per day, nor how safely he can transfer great ships, nor what will be the cost thereof.

A canal with locks would be as practicable at Panama as anywhere else; it would save large expenditures in the first building of it, but M. De Lesseps has decided never to have anything to do with a lock canal for ships, and his experience at Suez has convinced him more and more that a canal with locks will not answer the requirements of modern commerce and of the great ships in which it is transacted. During certain seasons of the year, when the large crops of California come to market, there might be days when sixty or more ships, delayed by storms, would arrive and want to pass at once. How could they be transferred through locks without great detention to some of them? Now wheat, indigo and similar shipments, are subject to rapid and great changes in price, in the markets of the world, so that the delay of a single day may cause much loss to the shipper or the consignee. What would he think of the locked canal, if the detention of his vessel at Panama delayed its arrival until his competitors had glutted the market, and put down the prices of his shipment?

It is quite certain that a sea-level canal will be more costly than a canal with locks, but should this consideration be urged, while bearing in mind the probable returns of the enterprise.

Now, according to the statistics presented by M. Levasseur to the Paris Congress, the annual traffic to be expected amounts to six millions of tons per year; this would be charged at the rate of $3 a ton, thus yielding a revenue of $18 000 000 per annum, which would give quite a sufficient return to the holders of the shares. Perhaps not to American investors, who are accustomed to great profits, but certainly a sufficient return to European stockholders, where money is cheap.

Besides, if $3 a ton is not sufficient, the canal company may charge a higher price. It is not, however, believed that the charge will be made more than $3 a ton. M. De Lesseps is opposed to any higher charges. He established a price of $2 a ton at Suez, and it has remained at that ever since.

M. De Lesseps is asked why he does not establish an office for his company in America. His answer is that the principal office must be in that country which furnishes most of the funds, and that if a majority of the capital is subscribed in the United States, he will be very glad to transfer the seat of his operations to the City of New York, or some other American city.

As soon as the compilation of the various notes of the cross-sections, borings, &c., are completed, and the reports, maps, &c., are published, the Technical Commission will take special pains to send full sets of them to the American Society of Civil Engineers.

And now, in conclusion, allow me to thank the society for the kind, the more than kind, the hearty reception, which has been extended to us in New York, and for showing us the very interesting American works which we have seen. We did not expect, we were not prepared, for so cordial a reception. In fact, we had been told that the Americans looked upon M. De Lesseps with suspicion, and we had no idea of the boundless hospitality, wide as your own country, which awaited us. Messrs. Boutan and Dauzats, who sailed this morning for Europe, were very careful to impress upon me before they left, that I must say at least this much to you, and to convey their thanks, at the same time as my own, for the great kindness, which you may be quite certain shall never be forgotten by us.

I have left with the secretary two volumes, containing drawings and photographs of some works executed by our firm, the acceptance of which I beg from the Society.

G. W. Dresser moved that a vote of thanks to M. Dirks and to M.

Couvreux be passed, for the interesting discussion which they have given of the question, for their patience and kindness in answering questions, and for their able discourses. Seconded, and carried unanimously.

M. Dirks.—I wish to say that my stay in New York has been almost the happiest period of my life. That I hope that I may have the good fortune to come back again to "New Amsterdam," and that should any of you ever visit old Amsterdam, you call on me—that's all.

Discussion by Ashbel Welch.

Mr. President and Gentlemen,—You will remember that I asked M. de Lesseps the other night: "Why go to the enormous expense of making a sea level canal across the Isthmus, when a canal with two or three locks on each side of the deep cut could be made so much more cheaply?" In his answer he mentioned two objections to the locks; one was the cost of maintaining and operating them, the other the detention of the vessels. He remarked that locks might do very well for ships of small size, but not for such as would navigate this canal. In this the veteran diplomat follows public opinion, which, whatever his own opinion may be, his position compels him to follow.

I propose to point out, first, the great saving that may be effected by putting in three locks, each of 20 feet lift on each side of the deep cut; second, that the annual costs and detention by the locks will be very small in comparison with the saving; and third, how the largest ships that ever floated can be handled with as much certainty and safety as a rowboat.

I admit that if animal power, or the steam power afloat were to be used in handling the vessels, or human hands were to operate the locks, as I suppose is now the case on all canals in the world but one, I should agree with M. de Lesseps, or rather with present public opinion, that locks should be avoided at whatever cost.

Though I am sure the work on this canal cannot be done for the prices estimated by the engineers, I shall for the present purpose admit that those prices are correct.

Picking out of the estimate the items of cost that may be saved in whole, and apportioning those that may be saved in part by 60 feet lockage on each side of the mountain, the saving cannot be less than 350 000 000

francs, and probably much more. Most of the work under water, and other difficult portions would be avoided.

M. Dauzats stated the other night that the deep rock cut averages 180 feet deep for seven miles in length. By reducing the cut to 120 feet forty per cent. of the quantity would be saved, and considering the much greater cost per yard of taking out the bottom than the top, probably one-half the cost would be saved.

As the deep cut will doubtless take the longest time, it is probable that reducing the work in it one-half will reduce the time for completing the canal as much as one-quarter. The engineers say that "with good and judicious management the work can be completed in eight years," which means that it cannot be done in less. The locks would doubtless reduce this estimate to six years.

The locks should probably have 600 feet length and 80 feet width of chamber, with side pipes for filling and emptying 12 feet diameter, or what is very much better where the location permits, a large open channel on one side for filling, on the other for emptying. The prism of the canal should be enlarged above and below the lock so that the drawing of the water from the upper and discharging into the lower level should make no agitation of the water and no current near the lock.

This unnecessarily large size for present business adds but a very moderate percentage to the first cost, and almost nothing to the cost or time of operating. The waste of water in this case is of no account. Arrangements easy and inexpensive can be made beforehand for increasing the length without any interruption to the navigation, should that ever become necessary. My experience in lengthening locks has suggested how this can be done. The cost of six such locks, built in the best and safest manner, but without fancy masonry, may be seven or eight millions of dollars.

Unless a very great amount of property would be destroyed by the dam, to which our attention was called by Mr. Ward some time ago, it should be built as near the mouth of the Chagres River as a good site can be found, and raise the water from 20 to 80 feet, as the condition of property on the river above may permit. If the damages were $20 000-000, or even much more than that, there would still be an immense gain by it. It would make a safer and quicker navigation than a sea-level canal. Instead of a narrow canal with only passing places every 3 or 4 miles, involving some hours detention to each vessel, and a constant risk

of scraping the bilge on the slopes of the banks, vessels could go through an open lake, in deep water, without risk or interruption, and at much higher speed, and it would save much difficult and expensive work, and form a reservoir for, and discharge gradually, an immense amount of flood water.

The dam should be of timber cribs filled with stone, sunk on any kind of bottom, with an apron below of crib work 5 feet or 6 feet deep, filled with stone, except near the lower end, covered with logs parallel to the stream, carried down stream 150 feet to keep the excavation made by the water in the bed of the stream at a safe distance from the dam. Such cribs, unless undermined, are immovable, and being always wet, indestructible. The logs on the lower side might require protection from the teredo. In my long experience I have seen almost every other kind of work give way, but never such dams.

A dam 100 feet base, 80 feet high, with apron 150 feet long, 6 feet deep, would probably cost $500 per foot lineal, or 2 000 feet long would cost a million. This is 50 per cent. more per cubic foot of dam than the prices I am accustomed to. There is no difficulty in raising the water 60 or 80 feet by such a dam. If its whole height is 120 feet and base 150 feet it would cost $1 300 per foot lineal.

I judge from M. de Lesseps' raised map that a good site may be found in the right place.

The saving by the 60 feet lockage on each side being 350 000 000 francs, deduct the cost of the locks and dam, and the probable damages, and we have a net saving in construction of 300 000 000 francs or $60 000 000.

If the time without locks is 8 years, and the cost $168 000 000, as estimated by the engineers, and if one-eighth of that sum = $21 000 000 is set apart at the beginning of each year, then at 7 per cent., compounded every 6 months (which is far less than the experience of this country warrants us in expecting, especially in an enteprise regarded as so doubtful as this), the interest up to the time of completion will be ($21 000 000 × 3.04 =) $63 840 000. If the time with locks is 6 years and the cost $108 000 000, the interest at the same rate to the time of completion is $\left(\frac{108\,000\,000}{6} \times 1.686\right) = \$30\,348\,000$. The saving in interest by the locks is ($63 840 000 — 30 348 000) over $33 000 000. Add this to the $60 000 000 saved in construction, and we have over $93 000 000 saved in construction and interest up to the time of completion.

The cost per yard of the deep cut will be considerably reduced, in addition to other considerations, by giving more time to do the same quantities.

But there is a claim for deduction from this for the maintenance and operation of the locks and for the detention of vessels passing them.

The principal expense of maintaining locks is on the wickets in the gates. I would have none in this case, but feed and empty by channels on each side, or, where the locations do not permit that, large side pipes.

The largest calculation for cost of maintenance and of operating in the manner I propose, cannot exceed $50 000 per annum for each lock, making for the whole $300 000. As for accidents, there is less danger with suitable appliances for handling than on any other 1 000 feet in length of the canal; for the vessel is under stronger, more perfect, and more expert handling than anywhere else.

The detention, as shown hereafter, need not be more than half an hour at each lock, or three hours in all. With ordinary vessels it would be much less. The present California ships carry 3 000 or 4 000 tons measurement, or about 2 200 tons actual weight. Taking all ships, great and small, they will probably average at least 2 500 tons weight, or 4 000 tons measurement.. If 6 000 000 tons measurement passes the canal per annum it will then require 1 500 vessels; if 6 000 000 weight, 2 400. But I can afford to admit for this purpose that there will be 10 000 000 tons in weight per annum in 4 000 vessels, and that the detention involves a loss of $15 per hour. Then the whole loss from detention is $180 000 per annum.

Add these two sums and we have as an outside calculation $480 000 per annum against the locks. At 7 per cent. this represents a capital of a little less than $7 000 000; at 6, $8 000 000; at 5, $9 600 000. I can afford to call it $10 000 000.

Deducting this from $93 000 000 we have $83 000 000 net saving. The estimate for a sea-level canal being $168 000 000, and the interest during construction nearly $64 000 000 (and both will be greatly exceeded), the whole cost up to the time of completion is $232 000 000.

The $83 000 000 net saving, after deducting all disadvantages, is considerably more than one-third of the whole estimate.

If so much can be saved with so little loss, by 60 feet lockage on each side, why not have more lockage? I cannot answer, without knowing

whether the water can be always at command so high up ; and not knowing the ground, how expensive the feeder might be to reach the summit. There will doubtless be abundant water at all times in the pool above the great dam at the height of 60 feet above tide, perhaps much more.

As I have already said, if animal power was to be used in hauling large vessels into and out of the locks, or if they were moved only by their own engines, or if the gates and valves were operated by human hands, all of which is, as I suppose, still the practice in every canal in the world but one, I should agree with M. de Lesseps that for a canal navigated by large ships, locks should be avoided whatever the cost might be.

It is under such experience that the present public opinion against locks was formed. We have all seen the slow and sometimes dangerous operation of getting a big ship into her berth or dock. Though in the case of a canal lock there is no tide across the ship's course, the delay and risk with the ordinary mode of handling are so great as to be avoided at any cost.

In my younger days I had charge of the Delaware & Raritan Canal, which connects the waters of New York and Philadelphia. The locks have 24 feet width and 220 feet length of chamber. They were calculated to pass vessels of nearly that length, but terminal and connectional considerations prevented the general adoption of such long vessels. The locks commonly pass two boats of about half their length, often having an aggregate weight of a million and a quarter to a million and a half of pounds. I was so much impressed with the slowness and risk of handling these heavy vessels and operating the locks in the old way, and their consequent low limit of capacity, that for many years I had it in contemplation to use steam upon the walls to haul the vessels in and out and open and shut the gates and valves. In 1868 the canal nearly reached its capacity with the then arrangements, and in that year and the next I carried out my long contemplated plan. The capacity of the canal was increased 50 per cent., and accidents previously not uncommon are unheard of since. As this was early a pet plan of mine, I have watched it ever since. I was surprised in 1869 to find no such contrivance for hauling vessels at any of the London or Liverpool docks, though they had hydraulic power on the spot. I learn that some such contrivance has come into use there since.

The whole apparatus is very simple. The engine has two small cyl-

inders, working cranks at right angles on the same shaft. This gearing down through some intermediate wheels works a drum 3 inches in diameter, which moves a one-inch wire hauling cable, along the face of the lock wall, after passing around sheaves above and below the lock. The speed of the rope is half that of the pistons. This hauling cable is connected with the vessel by a rope fastened at one end to a ring in the cable, and at the other to a timber head on the vessel. The cables were made by Roebling and have never broken. The engines and machinery were made by Mr. Wm. Cowin, at the Lambertville Iron Works. The engineer stands on a sheltered projecting platform over the edge of the lock, some 8 or 10 feet above the top of the wall, and has all the levers for every operation in reach without moving from his position, or turning his face away from the vessel. Though he has so many pullings and haulings and openings and shuttings, they are not simultaneous, but in succession. The whole operation is thus performed by a single expert, trained to this work—sheltered from the weather, instead of inferior and inexperienced men, whether on the vessel or on the walls, sometimes exposed to the storm and often failing to act in concert.

I shall not describe the apparatus now used in detail, but state what I think should be used in the proposed Isthmian Canal.

Suppose a ship may possibly pass equal in weight to a rectangular box 48 feet wide 500 feet long, with immersed depth of 25 feet; equal to an actual ship of 48 feet beam, over 600 feet long, drawing 26 or 28 feet. The displacement of such a box would be 600 000 cubic feet, and if in fresh water, the weight would be 37 500 000 pounds. To make the case still more extreme, call it 40 000 000 pounds.

To overcome the inertia of this mass and give it a velocity of 2 feet per second in 60 seconds, or to stop that velocity in 60 seconds (disregarding the resistance of the water), the acceleration or retardation must be $\frac{2}{60}=\frac{1}{30}=0.033$ feet per second. As the whole weight gives an acceleration of 32 feet per second, it requires $\left(\frac{W}{30}=32\,p\;.\;.\;p=\frac{1}{960}W=\right)$ 41 666 pounds, to give such ship a velocity of 2 feet in one minute. This requires an iron wire rope 2½ inches in diameter, to transmit the power. A steel rope may be smaller. As the movement is so slow and these extreme weights seldom moved, and with the contrivance hereafter mentioned, the rope need not be so large as if running rapidly and constantly.

The power may be generated by an engine of two cylinders each 16 or 18 inches diameter, the pistons ordinarily moving 240 feet per minute. This power should be used in succession to haul the vessels in and out; to haul and hold the four breast lines; to open and shut the main gates; to open and shut the valves that admit and discharge the water to fill and empty the lock; to operate the brake hereafter mentioned; to handle the light shears used to pass shore lines on board a vessel, not yet otherwise in reach; to lift out and replace gates and valves when necessary, and to raise the guard gate hereafter mentioned when necessary.

An iron pipe 2 feet in diameter must be placed under the bottom of the upper level, on the upper side of the head wall, through which the wire ropes pass that carry the power from the engine to the other side of the lock.

The part of the hauling cable that moves along the face of the lock and never reaches the drum, should be 4 inches in diameter, covered so as not to be injured by friction, and a friction brake worked by the engine should be ready to be applied to it near each end of the lock. If it is ever necessary to use this brake it will stop 40 000 000 pounds moving 2 feet per second, in 15 seconds; moving in that time 15 feet, and the strain is, $= \frac{W}{32 \times \frac{2}{15}} = 166\ 666$ pounds. A snubbing line of the same size should pass from a ring in the cable to the quarter of the ship, in stormy weather.

Breast lines, one on each bow of the ship, and one on each quarter, should be used to hold the ship firmly in her course while going into and out of the lock and in her position while the lock is filling and emptying. These should probably be 2½-inch wire ropes, hauled and held by the engine. Several plans suggest themselves, simple and sure in their operation, of traveling apparatus running in grooves, and moved by the engine, for carrying along these lines on shore.

Each ship on approaching the canal should be provided with strong lines with a ring or hook at one end to project through the hawse holes or over the bulwarks, the other end made fast to the bitts or something else. To these rings or hooks corresponding hooks or rings on the breast and hauling lines handed aboard by the shears can be attached without delay. These lines may be given up on leaving the canal. Large ships should not be allowed to touch the gates or walls, and it is easy to prevent them.

There should be a strongly trussed guard gate working on a horizontal hollow quoin, lying under the water at the head of the lock, which can be raised in a few seconds by the engine. I have found such of great use.

Steamers may, perhaps, sometimes go out by their own power, but not in. They have not such quick and delicate control of their power. Everything should be done by the one expert, always in his sheltered commanding position. Though he has so many things to do, he does only one at a time.

The lock when technically "empty," should have four feet water under the bottom of the deepest vessels, so that they can move easily, and not surge when the water comes in rapidly in filling.

To guard against the possibility of detention in case of accident to the gates, spare gates should be kept on hand. Shears should be always ready for use on the side where the engine is, opposite to each pair of gates, and then the engines can take out the old and put in the new gate without an hour's detention. Some of these precautions are against difficulties that will seldom or never occur.

It may be said that all this requires much watching, that the machinery may get out of order, and that it is expensive. In fact, every part of the machinery is of the simplest kind; the experience of 11 years is that it does not get out of order. I never heard of an accident or failure. As to cost, it is well worth while to spend thousands in order to save millions.

It may be said that we cannot reason from handling 1 500 000 pounds up to 40 000 000. The difference is, that in the latter case the power must be greater, the apparatus stronger, the motions slower, and even the slightest concussion must be (as it can be) absolutely prevented.

When we see a steel converter handled with so much facility and six tons of melted metal poured out with as much ease and certainty as a lady pours out a cup of tea, we need not be surprised that a ship, however large, can by the same powerful agency and proper appliances, be handled as easily and safely.

Hydraulic engines would be better than the direct application of steam, but more expensive.

Before putting up my lock operators 11 years ago, I calculated every resistance—strain, power and motion. After years of trial I do not think of a single thing I would alter. Nothing has failed or broken, and times

have not varied a quarter of a minute from the calculations. I, therefore, feel warranted in speaking on the subject with the utmost confidence.

The time required to pass the heaviest vessel will be about as follows:

Attaching the ship to the hauling cable, and attaching breast line fore and aft and on each side	1	minute.
Getting up motion of two feet per second and going sixty feet	1	"
Moving 840 feet at 2 feet per second	7	"
Stopping in sixty seconds	1	"
Securing vessel and shutting gates at the same time	2	"
Filling lock 6 minutes, (emptying 5)	6	"
Getting up speed, as before	1	"
Hauling out, if up stream 6, down 8; average	7	"
	26	"

Allow 4 minutes for slowing up, &c., before reaching the lock, and we have half an hour.

With 12 feet feeding and emptying pipes on each side, the lock can be filled or emptied in 5 minutes; with open channels on each side of the lock, much sooner. A lock on the upper Lehigh, 27½ feet lift, was emptied in a minute and a half. But it may not be always prudent to fill under 6 minutes. The valves are under such absolute control of the engineer, who watches the effects, that he can fill as gently or as rapidly as circumstances require.

Smaller vessels can be safely passed much more rapidly.

On the Delaware & Raritan two loaded boats may be passed one way, and two light boats the other, in 16 minutes—the loaded in 9, the light in 7. It is commonly done in 18 minutes. The locks are filled or emptied in 2 minutes.

Pumps to be worked by the engine should be on hand to give access to all the works under water, for inspection or repairs.

If single locks should become insufficient in 20 years, or longer locks be required, the present value of the cost of building them at that time, is only one-fourth of that cost. It is as econom cal to pay 4 dollars 20 years hence, for a thing you don't want till then, as to pay one dollar for it now.

To slackwater the Chagres and build a half dozen locks would make a navigation safer and speedier than a sea-level canal. The speed could be higher in the open river, or rather lake; vessels would not have to lie still, perhaps nearly half the time at the passing places, and they would have less chance of having their copper scraped off against the slopes of the banks. If the canal were made without locks, the best thing to be done would be at once to put in one at each end, so as to deepen and widen the canal, make the safe speed higher, and enable vessels to pass each other almost anywhere. The danger at locks can be made less than on any other part of the canal.

Canal engineering and canal management are still running in the grooves established in the age of Louis the Fourteenth. The few canals now made are not such as require skill, but main strength and money. The improvements that have been made are unknown to the great world, because the world in these *uncanalling* days has taken no interest in the subject. Little about them has got into the books, for it was useless to put there what nobody would read.

Hence an uninformed public opinion objects to locks for large ships, because such ships have heretofore been handled at wharves and docks by hand, or without such apparatus as can easily be applied at a lock built with a view to such application. I would no more think of passing a ship through a lock, or holding it in its place by animal power, than of rowing it by hand across the Atlantic.

"An artificial strait:" "A watercourse without impediment," and all such phrases have a magnificent ring, but to spend eighty or a hundred millions of dollars for an idea—to satisfy an unreasoning or uninformed public opinion, is bad engineering. That is the best engineering, not which makes the most splendid, or even the most perfect work, but that which makes a work that answers the purpose well, at the least cost. The demand of the public for a canal without locks, reminds one of Charles Lamb's youthful Chinaman, who for want of knowing any cheaper way, burned down his house to roast his pig.

A canal is not a monument, but an enterprise. No engineer is warranted in building a monument to himself with other people's money. Besides a splendid work, more expensive than is necessary to answer the purpose, is a monument that confers no credit on the builder. To make an enormously expensive work, when a cheaper one skillfully made and operated, would answer the purpose even better, is at best a magnificent

mistake, just what Stephenson said his Victoria bridge would be, if Roebling's Niagara bridge succeeded.

M. de Lesseps, by presenting his plans to this Society, has invited criticism. It is our duty to give it fearlessly ; and it is our duty when we are sure, from our own experience, that public opinion on engineering questions is mistaken on any point, to endeavor to set it right

To admit, that with all the powers and appliances now at our command, we cannot produce apparatus that will handle the largest vessel that ever floated, or that ever will float on the ocean, with the same facility, certainty and safety, that a steel converter is handled, is a disgrace to the engineering of this, the eve of the twentieth century.

Discussion by WILLIAM E. MERRILL.

I have read with great interest the discussion, in the January number, of Transactions of Inter-Oceanic Canal Projects, especially the paper by Mr. Evans. I would like to make a few remarks or points suggested by his discussion.

Like him, I have had a great deal to do with locks and dams, and like him I am afraid of them. In the Valley of the Ohio we have many rivers that are locked and dammed, all of which have a record of more or less disaster; and we have several, as the Kentucky, the Wabash, the Guyandotte, which once were locked and dammed and are so no longer, having succumbed to time and flood.

I agree with Mr. Evans that 1½ hours a lock is not too much for a first-class ocean steamer. I had an experience at the New York wharves with the *Celtic*, similar to the one which he had with her sister ship the *Britannic*. I have also seen large steamers enter the Birkenhead docks and I have passed through the locks of the Louisville and Portland Canal. From all of these I feel sure that 20 minutes to a lock is absurdly low. DeLagrené (*Navigation Interieure*) gives 23 minutes as the time for a tow-boat and its barges to pass through a lock on the Upper Seine, assuming that she is not detained above or below the lock. He says that a single barge without tow-boat requires 30 minutes.

Discussion by CHARLES MACDONALD.

When, at our last meeting, an enquiring member asked how it was proposed to provide for the Obispo, an affluent of the Chagres, which empties into it from the north, Mr. Dirks at once answered that, although

the stream was a small one, and could, without detriment, be allowed to enter the canal, yet, if upon further consideration it was deemed best to keep it out, it could be swung over the canal on a drawbridge carrying a trough; and when the passage of vessels necessitated the opening of the bridge, the waters could be dammed back by sluice-gates.

This original and ingenious suggestion affords a tempting inducement to an engineer like myself, whose experience has been more in the direction of bridges than canals, to join in the discussion of a subject which has became of such national importance, swinging into it as it were from the nethermost side, and quite willing to be dammed back, if need be, to make way for the unobstructed flow of more matured opinions.

We have had full discussion of the relative merits and demerits of the different routes proposed and of their probable cost, not only by those who have local interests at stake, and who may therefore be assumed to be more or less prejudiced, but by old and experienced hydraulic engineers, who could only be influenced in their conclusions by a sense of unbiased truthfulness, and an exalted estimate of the value to be attached to a professional opinion. Hence it may be assumed that those of us who have no personal knowledge of the difficulty of the problem to be solved, who have not been deprived of rest by anticipation of "earthquakes on the line of the San Juan," or consigned to a period of inaction under the depressing influences of that wonderfully varying "belt of calms" encircling the Bay of Panama; those of us, in fact, who must take our information second hand, may nevertheless have arrived at a reasonably clear idea of what is involved in the construction of a canal across the American Isthmus.

Thanks to the courtesy of that enlightened engineer, M. de Garay, we have been pretty fully informed of the workings of that professional gathering at Paris, which, under the guidance of a master hand, was enabled to reach conclusions with such remarkable celerity and apparent unanimity.

It is true, that body did not look with favorable eye upon the Tehuantepec route, involving, as it does, an overland trip through Mexico; but I am sure many of us who had the pleasure of listening to his eloquent exposition of the advantages of that route, will agree with him that if inter-oceanic communication can be successfully accomplished by means of a canal *with locks*, the precise amount of elevation to be overcome is not by any means the most important thing to be considered,

particularly when there are such potent geographical arguments in favor of a more northern route.

Mr. Menocal's paper on the Nicaragua route has been so fully discussed by members whose experience in canal construction enables them to speak with authority, that it would seem to be unnecessary to add to what has been said in order to illustrate more fully the utter inadequacy of the plan to the requirements of the case. A canal which would not accommodate vessels of the dimensions which are found to be the most economical at the present time, can scarcely be entitled to serious consideration so long as there is a possibility of obtaining an unobstructed water-way at the sea level, and upon a much shorter route. As regards the first cost of a canal with locks *via* Nicaragua compared with that of a sea-level canal, it seems to me that Mr. Menocal has seriously underestimated the difficulties to be overcome upon the route favored by him, both as regards quantities to be removed and cost per yard, to say nothing of the greatly increased dimensions which would undoubtedly be insisted upon if the work were ever undertaken, and the never-ending sources of expense attending the working of locks, certainly not less than 600 feet long by 60 feet wide. The question of first cost must undoubtedly receive due consideration, but Mr. Menocal's figures, for a canal at Nicaragua do not rise even to the dignity of a rough approximation, as Mr. Evans has clearly shown, and they may with propriety be consigned to the seclusion of a convenient pigeon-hole until such time as a sea-level canal is proved to be impracticable.

The San Blas route, located as it is upon the shortest line across the Isthmus and with good harbors at either end, would from these circumstances alone be very likely to attract favorable notice.

That it has not been as carefully surveyed as some of the other lines is certainly not the fault of Mr. Kelley, who, after having spent much time and money in a purely disinterested effort to fathom the mystery of the Isthmus, has finally arrived at the conclusion that, notwithstanding the colossal difficulties involved in the construction of a tunnel at least seven miles long, and big enough to pass the ships of the future, the route by way of San Blas is the best. In this he is supported by no less eminent an engineer than W. W. Evans, who is specially qualified to speak with authority upon such subjects.

But even if it be granted that the physical difficulties can be overcome at anything like the figures named by Mr. Kelley, there will yet remain

the commercial question, Can owners of ships be induced to risk them seven miles underground?

I confess to being somewhat skeptical on this point, without being able to give a scientific reason for my belief, or rather unbelief. Certain it is, that unless a structure presents the *appearance* of safety to the lay mind, it is very difficult to beget confidence in it; and I do not think it requires any argument to prove that the *fear* of possible accident from falling rock in a tunnel 150 feet high and of such exceptional length would deflect a large proportion of the tonnage which might otherwise be counted upon.

Whatever may be said in criticism of the methods employed at the Paris Congress, it is beginning to be admitted, perhaps in undertones as yet, but nevertheless with growing force, that the decisions arrived at, so far as they related to engineering questions, were founded upon sound principles, and unless some new developments take place outside the range of professional investigation, they must eventually be accepted as conclusive in determining the direction of active effort in the solution of this great problem.

M. de Lesseps, whether he be called diplomat or engineer, has undoubtedly proved himself to be possessed of a genius for affairs which is satisfied with nothing short of a comprehensive and complete accomplishment of whatever he undertakes; and in the treatment of this question, I believe he has arrived at the only conclusion which will stand the test of vigorous investigation; and that a sea-level canal at Panama is not only physically practicable, but it is the only expedient by which the commerce of the world can be *permanently* and *materially* benefited, so far as isthmian communication is concerned.

The cost of such a canal has been estimated by engineers whose experience in similar work eminently qualifies them for such duty; and when we are assured by Herr Dirks that he is willing to stake his reputation on the possibility of constructing the canal at Panama for a total sum of $168 000 000, we cannot but assume that the probabilities are in favor of the accuracy of the figures given.

But there are two features of this question which lie outside of and beyond the exclusive domain of the engineer, although engineers may refer to them as possibly of sufficient importance to overshadow the professional difficulties altogether. I allude to the contingent expenses attending the raising of the money to carry out the work; and to the revenue to be expected.

First, as to contingent expenses:

It is scarcely necessary to remark that the contingencies attending a work of this magnitude are likely to be very great, and quite as complicated in their estimation as the determination of the revenue.

The Suez Company was organized with a capital of $40 000 000 in 1858, but the capital account on the completion of the work was $91 500 000, or more than double the original capital stock.

If we apply a similar ratio to the Panama scheme, with an original capital of $120 000 000, as proposed by M. de Lesseps, we should expect to find the final cost reach the neighborhood of $300 000 000; and I am inclined to think that the figures will exceed, rather than fall within, this limit. But as engineers, we would certainly not be accepted as a competent tribunal of last resort in matters pertaining to contingencies; and it is for this reason that we may, with propriety, leave the further development of the issue in the hands of such an one as M. de Lesseps, whose experience in other and more varied spheres of action justly entitle him to command the respectful attention of capitalists, and the glowing admiration of the engineer.

Now, as to revenue: The Committee on Statistics, at the Paris Congress, estimated the canal tonnage as follows:

From and to the United States	2 000 000 tons.
" " " England	1 500 000 "
" " " France	356 000 "
" " " other countries	356 000 "
New traffic, Europe to the Orient	1 333 000 "
Estimated present tonnage	5 095 000 "

But, as it was assumed that the canal would take 10 years in building, and that during that time traffic would increase at the rate of 5 per cent. a year, it was stated that the total tonnage between the Atlantic and Pacific upon the opening of the canal might be expected to amount to 7 250 000 tons annually.

It was not claimed, however, that the whole of this would pass through the canal. Indeed, the Committee uttered a distinct note of warning against the assumption that either in the first year, or in subsequent years, this amount of tonnage could be relied upon to pass the canal. It was stated to be as the total volume, the reservoir from which

traffic was to be drawn, and how much of it would go by other routes, or how much through the canal, would depend on trade considerations which the Committee did not feel warranted in assuming.

From which it will appear that the estimated revenue of $18 000 000 upon an assumed tonnage of 6 000 000 tons is based upon extremely imperfect information.

It is understood that the Bureau of Statistics, at Washington, has been compiling some statements upon this subject for several months, but has not yet arrived at definite results. We are promised copies of them when completed, and it is not impossible that they may show that to some extent the Paris Congress, for want of better knowledge, was compelled to draw upon its imagination for its facts.

The only precedent we have upon which to base assumption is the experience at Suez, where we find a canal connecting inland waters, teeming with an immense local traffic, so to speak, and most favorably situated for facilitating the intercourse between 200 000 000 of people in India and the governing country, England; and yet the tonnage at Suez does not much exceed 3 000 000 of tons per annum, the exact figures from the date of opening being

Year.	Ships.	French Tons.
1870.....	486.....	654 915
1871.....	765.....	1 142 200
1872.....	1 082.....	1 744 481
1873.....	1 173.....	2 085 072
1874.....	1 264.....	2 423 672
1875.....	1 494.....	2 940 708
1876.....	1 457.....	3 072 107
1877.....	1 663.....	3 418 949
1878.....	1 593.....	3 291 535

If we contrast the geographical conditions at Suez and Panama, the comparison would be very much as if we were to take the business on the New York Central & Hudson River Railroad as a guide in estimating a probable traffic of the Northern Pacific Railroad—the one a trunk line passing through a rich and thickly settled country, and the other a pioneer of civilization, pushing out into the trackless prairie, drawing with it a tide of emigration, and opening new and unexpected sources of wealth; yet from this very comparison we may, perhaps, be the

better able to judge of the commercial prospects of the Panama canal, while it is more than probable that if that canal were opened to-day from the Atlantic to the Pacific, there would not be a tithe of the estimated traffic ready to make use of it. Nevertheless, we are to bear in mind that in the ten years which must ensue before it can be built great developments in trade and commerce are to be expected, and particularly will this be the case with our own coasting trade between the Atlantic and Pacific States.

Who shall say what the amount of that increase may be? Who, that is at all familiar with the development of the Great West, will pretend to forecast the commercial balance-sheet for the year 1890? May we not assume, therefore, that as regards revenue, there will be wide differences of opinion? And inasmuch as the capital necessary for the construction of such a work would be obtained, if at all, from sources outside the range of engineering influences, it will be quite unnecessary for us to discuss this branch of the subject further.

Discussion by Ashbel Welch.

I understand my friend who has just sat down to indorse the sea-level plan of M. de Lesseps for a ship canal from ocean to ocean through the Valley of the Chagres, rather than a canal with locks, on the ground of the great cost of construction, maintenance and operation of locks, the great delay in passing them, and the risk of injury to the vessels while passing.

To avoid the locks, M. de Lesseps proposes to build a narrow, far underground, enormously expensive canal, too narrow for large ships to pass, except at passing places averaging 5 miles apart, sunk under the bottom of a valley sometimes flooded 45 or 50 feet deep, with artificial rivers hanging over it along the hill sides to divert the flood water, which are always liable to burst their banks, with the most disastrous consequences to the canal and everything in it.

The first thought of an American canal and river engineer, on looking at M. de Lesseps' raised map, is to convert the valley of the lower Chagres into an artificial lake, some 20 miles long, by a dam across the valley at or near the point where the proposed canal strikes it a few miles from Colon, such as was advocated by Mr. C. D. Ward.

To avoid the expensive, dangerous, and tedious canal proposed by

M. de Lesseps, I would make such an artificial lake ; its surface, say 80 feet or more higher than the ocean, which, if M. de Lesseps' raised map is at all correct, would give a ship channel 40 or 50 feet deep, and more than a quarter of a mile wide in the narrowest place. I hear the objection that the Chagres is a crooked stream, and could not be navigated by long ships. That is quite true. Of course, I would not merely slack-water the *river*. But the *valley* is direct, without sharp turns, and the ship channel would occupy the whole of that valley, not the mere bed of the stream that meanders through it.

To make this lake 80 feet high and reach it, would require a dam which might be 120 feet high from the bottom of the mud of the Chagres for a few hundred feet in length of dam, and which should reach from rock to rock, and 4 locks averaging 20 feet lift each.

A crib dam 200 feet base, 120 feet high from the bottom of the mud of the river, with crib apron averaging 15 feet deep and extending 300 feet down stream, from the dam proper, would cost in a wooded country here, including filling all cribs with stone and gravelling on the upper side of the dam, from $1 500 to $2 000 per foot lineal.

On the Isthmus it might cost $3 000 per foot lineal. If the Chagres is 1 000 feet wide, this makes $300 000. If the distances to the high land on each side are 2 000 feet, the cost per foot lineal for a rubble masonry dam, with the gravelling above it, may be $400 per foot lineal, making $1 600 000. Total, under $2 000 000. For the present purpose we will double this and call it $4 000 000.

Mr. Evans, in his very able paper advocating the San Blas route in preference to the Chagres valley, speaks of dams as hazardous, and of the destruction by a great flood of the dams on the upper Lehigh. These crib dams proper were NOT injured by the flood. The water overflowed, and in consequence carried away the embankments between the ends of the dams and the highlands, and carried away almost everything else but the crib dams themselves, which stood unharmed in the midst of the torrent.

It would also require to get up to the lake thus formed, four locks averaging 20 feet lift each. These locks, say 600 feet by 80 feet chamber, with high level basin on one side, and outlet channel on the other, with 10 openings, 6 feet by 10 feet through each wall, to fill and empty in 2½ or 2½ minutes, when there is nothing in the lock, or with a ship in the lock to fill safely in 6 minutes and empty in 4 minutes, and steam

engine on the wall, and the appliances to open and shut all the gates and valves, and haul and handle the ships by steam, would cost from a million and a quarter to a million and a half of dollars. The maintenance of the locks would be very little, the things that cause nearly all the expense of maintaining ordinary locks being avoided. The operating including the maintenance of machinery and manning the locks might reach $50 000 each per annum. Roughly, we may say that the cost of the lock and operating apparatus, and the sum of which the annual expense of maintenance and operation equals the interest, is two millions of dollars for such a lock, or one hundred thousand dollars per foot lift. The 4 locks to get up from the Atlantic to the lake, and the four to get down into the Pacific, would cost for construction, maintenance and operation equivalent to a capital of $16 000 000.

This would require the re-location of the Panama Railroad for some 20 miles on a higher level. An outside calculation for this would be $250 000 a mile, making $5 000 000.

Some villages of native huts, and some banana patches, would be overflowed. This could not be worth many millions, if even one. But if it would cost twenty millions for damages, it would be money saved to pay it.

The locks, dam, and damages, might cost, including the principal, of which annual expense is the interest, thirty millions of dollars.

M. de Lesseps estimates the cost of his canal at $168 000 000. Most canals that I ever knew, or knew about, have cost very much more than the estimate. They cannot be estimated as railroads can, there are so many uncertain and unforeseen items, especially the very heavy item of pumping, and others arising from the work being so low down in, or under the bottoms of the valleys. The Suez Canal, I understood, cost double the estimate. I should add 50 per cent. to the estimate named, making it $250 000 000.

The locks and dam would save nearly all the artificial canal, some of it through rock, cut for 20 miles along the Chagres; it would diminish the average deep cut 7 miles long, from 180 feet to 100 feet deep, and decrease the cost of the rest of the work a good deal. I suppose it will hardly be questioned that the cost on the plan I propose would be 40 per cent. less than the thorough cut, that is, $150 000 000. I would not, in any case, dispense with the dam and reservoir to hold back the storm waters of the upper Chagres.

If the canal costs $250 000 000, and takes 10 years to complete, and one-tenth of the cost is set apart at the beginning of each year, then the interest at 7 per cent. compounded every six months, will be over $122 000 000 up to the time of completion. This makes $372 000 000.

If the canal costs $150 000 000, and it takes seven and a half years to finish it, and $20 000 000 are appropriated at the beginning of each year, then at the same rate, the interest up to the time of completion, is a little over $46 000 000. Add this to the principal, and we have $196,-000 000; the difference is $176 000 000. Roughly, the cost by the latter plan would be one-half as much by this as by the other plan.

The first objection to locks is the great cost of their construction, maintenance and operation. The cost of maintenance of a ship lock itself, properly constructed, is very little. The great cost of construction and operation is freely admitted. Twenty million of dollars is a great deal of money, but if you can save a hundred millions by spending twenty, then it is economy to spend it.

The particular point that I wish to make is, that the canal, with the lake and the locks would not only be cheaper than the thorough cut, but far better when done; and that too in the very particulars in which it is objected to; the speed and safety of the vessels, and the safety of the canal itself.

I understand the calculation to be that vessels while moving through M. de Lesseps' canal can go three miles an hour, and that the detentions at the passing places for large vessels will be at least fifteen hours. This makes the whole time 30 hours.

In the lake, large ships and steamers can probably go 5 to 10 miles an hour, more easily than they can go 3 in the canal. This makes 2, or at most, 4 hours. To pass through the 8 locks we must allow 4 hours more, The rest of the canal, 25 miles, requires at the same rate as in the thorough cut, about 17. The sum of these is 23 to 25 hours, against 30 by the sea-level canal.

As M. de Lesseps says it takes an hour and a half for a ship to pass a lock; it is proper that I should explain how it can be done in less than a third of that time.

I here repeat what I said on a former occasion, that I would no more think of making a ship canal, with locks to be worked by hand, or of hauling and handling the ships there by human or quadruped power, or by their own steam afloat, than I would think of rowing a ship by hand

across the Atlantic. A puff of wind would give them a motion which could not be controlled. The steam afloat acting against unstable water, is too uncertain and too slow to change, and therefore, unsafe. If I knew of no other way of operating locks and handling vessels at them, then I should agree with him that locks should be avoided at whatever cost, and at whatever other sacrifice.

The decision of so many eminent and able engineers in favor of a scheme so very objectionable in so many respects as this sea-level canal, is evidently owing to not considering that there is an agent at command sufficiently powerful not only to operate the largest lock ever dreamed of, but to move, handle and hold the largest ship that ever floated, and that with appliances of the simplest kind, and quick and certain in their operation. Of course, I mean steam, not afloat, but on the lock wall, where it has a fixed base of operation. All the processes are performed by a single expert, who, from his elevated and sheltered position, does everything, and has every lever within reach without changing his position or turning his head.

This is not a mere theory or untried project, but I devised it many years ago, and put it in operation eleven years ago, and it has been in successful operation ever since. True, it is on a much smaller scale; but on the other hand, it is not on locks best adapted to the purpose, which a ship canal lock can and should be, and the apparatus is so simple that it can be applied with ease and certainty on any scale.

The steam "lock-operator," as I have christened it, removes all the objection to locks, except the cost of construction and of operation; and it is a question in each case that arises whether more than that cost is saved in some other way; and it is a question in each case whether more time is saved in some other way than is lost by the locks.

Large ships, passing a lock, should be held firmly in every direction, and never allowed to touch the walls or gates. They should be hauled in slowly ; out as rapidly as the stationary power will move them. Their own steam should not be used except, perhaps, in going out, and their rudders should not be relied on, nor their own crews, except merely to hook on the wire rope lines.

I shall not describe the apparatus now, having, on a former occasion, pointed out generally its mode of operation, and intending, with the indulgence of this Society, to submit to them, on a future occasion, what I think the proper plan for a ship canal lock and its "lock-operator."

M. de Lesseps, and others, infer that it is a long and ticklish operation to pass a ship through a lock, because it is so to get it into a dock or berth from an open river or bay. But the circumstances are very different. In the canal, the ship heads right to enter the lock from the first; in getting into her berth, from the river, she must commonly change her direction 90 degrees. In the canal there is no cross current, as often in getting into docks, and there need be and should be no current at all. In the canal, there is something fixed on each side to fasten to and pull from in every direction, which commonly there is not in getting into docks.

Though not myself in charge of them, I have long watched the handling of ships, and I once had much experience in handling vessels a great deal too large to be moved, without delay and danger, by animal power. I know from experience, not only the very great saving of time, but the immunity from accident, resulting from the adoption of the stationary steam apparatus. A ship passing a lock properly constructed and so provided, ought to be quite as safe as in any other part of the canal.

The very large and numerous gates by which I propose to admit and discharge the water through the sides of the lock, are, of course, intended to be opened and shut only by steam, and to hoist, not revolve.

The great risks to which the low-level canal must always be exposed and the greater safety of the lake is, perhaps, even a stronger argument in its favor than the saving in cost of construction.

It is proposed to intercept and divert the flood waters of the many streams that pour into the valley of the lower Chagres, by artificial rivers along the sides of the valley. A very little experience with such, must impress any one with the great danger of their bursting their banks, unless made in a manner and of dimensions enormously expensive, and evidently not contemplated in this case. Rivers, at any rate American rivers, are always doing something they never did before, and that nobody ever expected they ever would do. This very Chagres is said to have risen fifteen feet higher last November than in any of the tremendous floods ever previously known, thus discharging 50 or 100 per cent. more water per second than ever before known. The Delaware, which always had the reputation of a well-behaved river, rose to a very extraordinary height in October, 1787, during, what tradition calls, the "Pumpkin Fresh." In 1841 there came a flood that rose so much higher than the pumpkin fresh, as to discharge full 50 per cent. more water per second.

If the floods should break into the canal (as they surely will), they would not only fill it up, perhaps, for a long distance, and stop the navigation for a long time, but destroy the ships that might be caught in it. With such a current as would be created, any ship would be helpless, one end would fasten on one side, the other end on the other side, and on the subsidence of the water the ship must break in two or be ruinously strained. A large vessel is a very helpless thing in a small channel with a current. An effort was once made, within my knowledge, to navigate a canal feeder 60 feet wide on the surface, and 6 feet deep, with a current of only one foot per second, by schooners 80 feet or 90 feet long, 20 feet or 22 feet beam, drawing 5 feet water. In going with the current the bow often got fast against one bank, the stern against the other. On the Raritan, 30 miles from here, the steam tugs do not attempt to tow loaded vessels with the tide through the narrow part of the river. I have spent, in my younger days, many anxious hours in guarding against the irruption of high level waters into a canal, and many weary days and nights in repairing damages from them.

If the lake is formed, the great dam across the upper Chagres will still be necessary, and, doubtless, other dams to hold back the floods of some of the other rivers. But much of the storm water may be admitted without danger or inconvenience. To raise such a lake, an admissible height would take a great deal. Quite a current would be admissible in a channel so straight, broad and deep. But I am not prepared to say that even with the lake and dams the risk and inconvenience from the floods would be entirely overcome.

The large extent of the water-shed of the Chagres must be a very serious objection to a navigation through it upon any plan. I have never formed, much less expressed, an opinion which of all the proposed routes should be adopted, or whether the time has come to make any canal at all. I only insist that upon whatever route the canal is built, the best plan shall be adopted, and that an enormous amount shall not be expended to make a very imperfect and precarious navigation in order to avoid so slight a difficulty as half a dozen locks.

I confess to a prejudice in favor of the San Blas route. Perhaps it is partly from a prejudice in favor of its esteemed advocate, Mr. Kelley. The consideration that there are no floods to fear is one of immense importance. That it may be a sea-level canal is not its great merit. If there is water enough I would put in a lock or two at each end, so as to avoid

too deep a cut in earth, which is always troublesome. Most engineers know how expensive it often is to maintain even a railroad through a deep cut. I would make the canal in earth cuts, when not too expensive, 120 feet wide at bottom and 32 feet deep, so that vessels could go fast and safely and pass each other anywhere. The only question is not the cost, but the time it would take to make the seven-mile ship tunnel. As to the cost, it seems to me it is in this case fairly and fully estimated. But interest, after a few years, eats up your resources very fast.

There is one very serious error into which, perhaps, all the projectors have fallen. It shows how ideas on canal-making still run in the old groove. They all propose to make the bottom of the canal level, and within 2 feet of the bottom of the large ships. Such a ship, with only 2 feet water under her, can only be moved with great difficulty, and very slowly. Worse than that, a little inequality in the bottom, such as a sand bar a few inches high, will give a sheer, always liable to injure the vessel, against the bank. Even when such a ship has a speed of only two miles an hour, the counter flow and the lateral flow under her bottom has a high velocity. Any difference in the facility with which the lateral flow escapes gives the ship a sheer. The unequal current and the greater resistance, where the water is the shallowest, will more than counteract the guiding force of sides, keel and rudder. Probably, judging from my own observation in another canal, much of the difficulty in the Suez Canal arises from the inequalities in the bottom made by the dredging machines. The bottom should be dished so as to give 4 or 5 feet water under a large ship, being, of course, carried down full width, at least as deep as the bottom of the deeper ships. The speed could then be increased by the same power, the vessel would have steerage way, her tendency would be to keep the middle of the canal, and the commotion in the water tending to abrade the banks would be very much reduced.

If the soil of the Egypto-Arabian desert will hold the water, the best way would be to put in a lock at each end of the Suez Canal, pump up the water, or bring it from the Nile, if practicable, make the channel over 40 feet instead of under 30 feet deep, and wide enough to pass easily everywhere, and thus enable steamers to pass in 21 instead of 42 hours, as Mr. Evans found it took, and then they could sell the dredging machines.

In deep rock cuts a much better canal could be made at the same expense by making it deeper, even at the disadvantage of making it a

little narrower than proposed by most of the projectors. Take such a cut now proposed to be made, 100 feet deep, 100 feet wide at the water line, and slopes ½ to 1, with 28 feet water. It would be a great improvement to make it 8 feet deeper at the centre line, so as to leave 36 feet water there, even if to keep the area of the cross-section the same the width at the water line had to be reduced to 94 feet or 95 feet. With the section, as commonly proposed, a ship, in the middle of the canal, 44 feet beam, drawing 26 feet water, would have 2 feet water under her bottom, and from 21 feet at the bilge to 28 feet at the water line on each side; with the section, as I propose, she would have 10 feet under her keel, and 18 to 25 feet on each side. In the former case she could not, in the latter she could, steer without difficulty. This is so obvious that it is strange it should escape anybody, and yet I confess I did not think of it till experience forced it on my attention.

From the foregoing considerations I am compelled to differ from my friend's conclusion, and believe that a very much better navigation than that proposed by M. de Lesseps can be built on the same route for much less money. To make a thorough cut canal through the valley of the Chagres would be to ignore the improvements of the Nineteenth Century.

Charles Macdonald.—In view of the fact that locks can be so readily utilized, how is it that the Tehuantepec route has not received more attention? It is true that there are about 750 feet elevation to be overcome, but it seems to me that we should have more light than we have had as to that route.

Ashbel Welch.—I do not know enough about the Tehuantepec route to express an opinion. That is a large amount of lockage to be overcome—750 feet. The first question is, have you got water enough? There are two difficulties in making canals—too little water, or too much water. The first question about the Tehuantepec route is, have you got water enough for the locks? I know nothing about it; but suppose you have water enough, then it is a question of cost and of delay. If, according to the calculation I have made—and I feel confident it is correct—taking into consideration the cost of construction and the cost of maintenance of the proposed locks, the money disadvantage of a lock is about one hundred thousand dollars per foot lift for such vessels as will pass through, and as should be provided for. I mean the first cost and the annual cost of operation capitalized. When I say that, I

do not mean locks of such lifts as are ordinarily made—eight or ten feet—I would have all the locks, when the location permits, at least 20 feet. If not too much embankment, I would go as high as 25 feet. I will not go higher, as at present advised, than 30 feet. I know of one such lock having been built and worked with perfect success, ease and safety and such a lock, within my knowledge, was filled and emptied in a minute and a half. There would be no difficulty in filling or emptying these in one and a half minutes. Filling in less than five minutes would not be proper when there is a vessel in the lock.

CHARLES MACDONALD.—There are about 550 feet of elevation more in the case of Tehuantepec than at Nicaragua, as I understand it.

ASHBEL WELCH.—That is if the Nicaragua Lake should be be raised three feet. It would be a great mistake to raise it only three feet, and then for several miles to sink the bed from ten feet down to nothing. Instead of doing that they ought to raise the surface of the lake twenty feet, and then they would have nothing to do at its bottom.

JOHN BOGART.—Mr. Adams says, in his discussion, that the summit of the Tehuantepec Canal, as projected, is 200 metres, or 656 feet, instead of 750 feet.

ASHBEL WELCH.—Double lockage gives 1 300 feet, that would cost $130 000 000 including the annual charge capitalized, provided the locks were such as I have spoken of.

CHARLES MACDONALD.—I thought that was only for the elevation—up and down. Does that include the whole canal?

ASHBEL WELCH.—For the lockage only. Locks are, of course, serious objections, if you can do without them. They are not necessarily fatal to this canal. You can calculate that it is a disadvantage of $100 000 to a foot lift. Now, for 1 300 feet lift, up and down, you can count the cost. Such locks as I propose, and such as ought to be built—for anything you build should be built to answer the purpose—would cost $130 000 000. I would sooner do that than make a canal below the bed of the Chagres River, with its deluges.

O. CHANUTE.—I would like to ask a question. I understood you to say that all vessels would be detained fifteen hours each in passing the Panama Canal, because they could not pass each other except at the passing places. Now, from the report of the Technical Commission, I see that the plan provides for a canal between Colon and kilometre 36 (the Atlantic Division), and between the 61st kilometre and Panama

(the Pacific Division), with a surface width of 50 metres—164 feet. Ordinary sailing vessels are only about 25 or 30 feet wide; steamers 40 feet; two such vessels should pass in these limits. Between kilometres 46 and 61 (the Summit Division), the canal width, at surface, is but 28 metres—about 92 feet. Here, perhaps, they could not pass each other; but there is no where else they could not do so.

ASHBEL WELCH.—It is true that small vessels could pass on the wider portions of the canal; but M. de Lesseps himself supposed that the vessels passing through the canal would be 520 feet long, and, I think, 48 feet beam. But in the wider portion of the canal, the bottom is not 90 feet wide.

O. CHANUTE.—The bottom is not.

ASHBEL WELCH.—The width of water at surface is not the point. The width at the bilge is. I do not think that they could pass two vessels of 48 feet beam.

O. CHANUTE.—They would not pass in a curve; but would they not pass on a straight line?

ASHBEL WELCH.—No, sir; they could not. They would scratch off the copper or paint.

CHARLES MACDONALD.—They may be made of steel.

ASHBEL WELCH.—They would scratch off the paint and injure the plates.

O. CHANUTE.—The dam, at the point it crosses the Chagres river, would be 80 feet high; would that lake in question, 20 miles up the stream, overflow the railroad?

ASHBEL WELCH.—It would overflow the railroad, requiring its relocation for twenty miles, costing, for aught I know, $250 000 per mile. I would say that was an extreme estimate. That would be five million dollars. As to the amount of damage to private property, I do not know. If it would save more than one hundred million dollars by the expenditure of twenty or thirty, it is a good bargain. There is not much private property to be destroyed.

JOHN C. CAMPBELL.—There are no considerable towns. The railroad company lease the land along the line of the road. A large quantity of bananas are raised there and exported to this country. I came home in a steamer a short time since and they had on board eighteen car loads of bananas, raised along the line of the road. But if the canal were built, the railroad would be of no use, and would have to be abandoned.

ASHBEL WELCH.—The money damage would only be the worth of the land, and there is no estimating the money value of that, or what the damage would be.

JOHN C. CAMPBELL.—It would not go up to twenty million dollars.

ASHBEL WELCH.—If you save one hundred million by investing twenty millions, you do well.

JOHN C. CAMPBELL.—You would save the whole by not doing anything.

Discussion by T. C. CLARKE.

I believe that a straight canal is better than a crooked one, that a short canal is better than a long one, and that a canal at sea level is better than one with many locks.

So far I believe M. de Lesseps is right, and if he can raise the three hundred millions of dollars necessary to build his Panama canal, I hope, for one, that he will succeed. At the same time I maintain that, looking at this question from the point of an investor, I should be very sorry to put any money in any canal which would cost over sixty millions of dollars.

My reasons are these: one of the most important questions is—what rate of tolls should be charged.

The rate proposed for the Panama canal, $3 00 per ton, measured upon a solid of the length, breadth, and depth of the vessel, is entirely too high. It is prohibitory for all sailing vessels, except those from New York, as the following figures will show.

Take the case of a guano vessel of 1 500 tons, from Callao to Liverpool. Her expenses, including insurance and interest on capital, I am informed, are about 80 dollars per day. The distance saved by a Panama canal would be about one-third of that via Cape Horn — 90 days by one, and 60 by the other—equal to 30 days. 30 days at $80, is $2 400 = $1 60 per ton. Three dollars per ton tolls would utterly exclude the 1 200 000 tons of vessels engaged in the guano and nitrate trades.

Take the case of a 1 500-ton ship, from San Francisco to Liverpool; the saving here would be as 9 to 16, or 120 days via Cape Horn, and 68 via canal, a saving of 52 days, $\times 80 = \$4\ 160$, or equal to about $2 53 per ton.

Vessels from New York to the west coast of America and to Asia

would save over $3 00 per ton. Steamers also, on account of their much greater expense per diem, could afford to pay $3 00 per ton.

The estimates of probable tonnage made by M. Lavasseur for the Paris Congress, are much too large.

He estimates 2 million tons from European ports to the East, which, I believe, would not pass through the canal at Panama, because the distances via Suez are so much less.

Liverpool to Melbourne	1 300 miles.
" to Yokohama	1 500 "
" to Hong Kong	4 500 "

—less by Suez than by Panama.

The effect of the trade winds would not overcome these differences for sailing vessels.

A canal at Panama, Nicaragua, or Tehuantepec would depend upon the trade between San Francisco and Europe, and the eastern ports of the United States, which for 1879 I find amounts to.... 568 738 tons.

Also for vessels engaged in the guano and nitrate trades, about	1 200 000 "
Tonnage of vessels in connection with Panama Railroad, about	450 000 "
And vessels from New York to west coast of America and to Asia, estimated average	781 262 "
	3 000 000 "

provided the tolls were not too high.

The expenses of repairs and maintenance of the canal, are hard to arrive at. An approximation, however, can be made from the reports of the Erie Canal, in which, before 1862, the total receipts from tolls were	$97 625 000
And the cost of repairs, maintenance, and attendance, but not enlargement, were	24 377 000

—or about 25 per cent.

If we add to this 10 per cent. for towage, and 5 per cent. for harbors and lighthouses, making 40 per cent., we shall not be far out of the way.

I estimate the probable net revenue of an inter-oceanic canal, based upon such tolls as the different trades could afford to pay, as follows :

Tons.			
570 000	San Francisco, Oregon, wheat, &c.	$2 00	$1 140 000
1 200 000	Peru and Chili, guano and nitrate	1 00	1 200 000
450 000	Steam, Panama	3 00	1 350 000
780 000	New York	3 00	2 340 000
3 000 000 tons average.		$2 01	$6 030 000
Deduct maintenance, repairs, towage, etc.,		40%	$2 412 000
	Net revenue		$3 618 000

—or not more than enough to return six per cent. on an expenditure of 60 millions of dollars.

Enough has been brought out in previous discussions before the Society to show very clearly that no inter-oceanic ship canal can be built for anything near the above sum.

If M. de Lesseps could induce the governments of Germany, France, England, and the United States, to furnish the necessary capital, build the canal and present it to the world, to be used free of tolls, and also guarantee its free use at all times, it would be one of the grandest achievements of the century, and its cost would be but a fraction of the annual expenditure of those nations for war purposes, but when he asks us to believe that a sea-level canal at Panama will pay six or even five per cent. on its cost, we must be permitted to doubt very much.

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CXC.

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PROGRESS OF WORK AT THE EAST RIVER BRIDGE.

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The work on the designs for the approaches to the East River Bridge was begun about January 1st, 1877. The Brooklyn approach has a length of 900 feet on the centre line, and starts from the street grade at Sands street, rising $2\frac{85}{100}$ feet per 100 to the rear of the Brooklyn anchorage, where it has a height of about 60 feet above ground. It is crossed by several streets at high angles, and has one curve at about 200 feet from Sands street. The width throughout is to be 100 feet.

The New York approach is 1 546 feet long, rising from grade at Chatham street, $3\frac{25}{100}$ feet per 100 feet to the rear of the New York

anchorage, where it is 68 feet above ground. It will be 100 feet wide for about 500 feet from the entrance, and 85 feet for the remaining distance. In Brooklyn all the streets will be crossed by box or plate girders. In New York, Pearl and Cherry streets, together giving an opening 210 feet on one side and 170 feet on the other, will be crossed by trussed girders; Cliff and Vandewater streets by semi-circular stone arches 51 feet 8 inches span; Rose street by a three-centred stone arch, 57 feet span; and William and North William streets by box girders.*

The architectural problem presented was one of considerable difficulty, owing to the requirements in the case. These were that the spaces underneath should be made available for storage or mercantile uses, thus enforcing the necessity of keeping the arches wide enough for this purpose; and requiring, in addition to this, that the structure should be imposing and harmonious in effect.

The design as adopted was a composite one, being based upon one proposed by the writer as to general features, but being modified by the commission of architects as to the style of the arches, and made somewhat more ornamental in detail.

The fronts are entirely of granite. The main features are, massive abutments at each side of each street projecting at the base about 7 feet from the spandrel line. These have an ornamental plinth. The shaft is finished in smooth pointed work with chamfered edges; and the whole is surmounted by facia, cornice, pedestal, and cap. The heaviest cap stones are 17 feet long, 5 feet wide, and 2 feet thick. Between the abutment piers the spaces are divided, so as to give arches varying from 17 to 31 feet span. The small piers between have slightly battered sides, and terminate in ornamental caps or imposts, from which the arches spring. The arches are of the Florentine style, being broadest at the key and narrowest at the spring, thus giving a pointed extrados. This style was adopted by the architects in order to fill up the spandrel space, and not leave so large an amount of dead wall. The key-stones in the largest arches are 8 feet high and weigh about 11 tons. The arches are finished in the same style as the shafts of abutments. The spandrel is of a darker granite, in regular courses, but rock faced.

The cornice over the arches has a dentil course below, surmounted

* This was afterwards changed and stone arches substituted. That at William street is a stone arch of 38 feet span and 6 feet 5 inches rise ; and that at North William street a stone arch of 40 feet span and 5 feet rise.

by a heavy projecting coping course, all in six cut work. (I should have mentioned that the plinths, caps, and pedestals are also of six cut work.)

The cornice is surmounted by an ornamental granite parapet 4 feet high.

The regular thickness of the exterior walls is 3 feet 9 inches. The division walls and interior of the abutments is of brick. The foundations are carried down where the bottom is sound to 3 feet 9 inches above tide, but where sound bottom is not reached at this depth, they go down until it is reached. In one place this was 9 feet below tide. It may be well to record here the finding of trunks of oak trees in the muck at this point, which had no doubt been buried for several centuries. The wood was perfectly sound, and was sawed up into walking sticks. The spot had been built upon for probably 200 years.

The foundations as far as finished were well spread, and, as far as practicable, in such manner as to give a uniform pressure throughout, not exceeding 5 tons per square foot when fully loaded. They were built of concrete, rough stone, and brick work. They were faced with brick always when coming next to a cellar space. When such facings were used tie walls were always carried across, so as to bind the mass together.

All the brick and stone work is set in cement mortar, and the limiting strain on brick in compression is fixed at 200 pounds per square inch. The floors are in this supposed to be loaded, including their own weight, with 450 pounds per square foot, and the roadway above with 100 pounds per square foot.

These are the *limits*, but the actual sections are considerably beyond these figures, and it is not at all probable that the loads mentioned will ever come on the floors.

The present condition of the work is as follows: In New York the stone work of the block next to the anchorage is completed, and in the next two blocks the stone and brick work are completed to the springing of the arches very nearly. This leaves three full blocks and part of another yet untouched, and will require nearly or quite two full seasons' work to complete them. In Brooklyn the work has made about the same progress, but, owing to the shorter distance, it can be finished in about another season.

Owing to the lack of funds the trustees have decided to do nothing more on the approaches at present, so that the time of completion is

indefinite. The part of the work in charge of the writer is the New York approach (the Brooklyn approach being in charge of Mr. G. W. McNulty), but he has deemed it proper to mention both approaches, as they are essentially the same work.

Before closing, it may be interesting to members to mention the methods pursued in setting the stone work. The first thing done in every case, as soon as the ground was cleared of buildings, was to carry forward two lines of railroad track running through the work and at a convenient distance either side of the centre line. Next two lines of derricks were put up, and strongly guyed in such positions as to reach all parts of the pits for excavation, and high enough to set all stone to and including the lowest arch stones. Then, since the walls on the New York side were to reach 68 feet above ground, and the cap stones about 74 feet, it was deemed desirable not to attempt the use of derricks further, but to use a traveling crane. The novelty of this consisted in the method adopted for turning the corners, as it had to set stone on three sides of a square.

The span of the trestle was 16 feet. At the inner angles corner posts were placed, carrying at their upper ends cast-iron turn-tables, the castings being in the form of a T, with the cross about 6 feet long, and forming a portion of the track, and the vertical portion cast hollow and slightly conical, so as to turn freely on the post.

The outer track was carried around with a curve of 16 feet radius. When the crane had traveled forward so that the inner pair of wheels were balanced on the turn-table, a tripping piece threw them suddenly out of gear, and the outer wheels then traveled around the curve while the inner end of the machine pivoted on the turn-table. As the outer wheels reached the tangent again the inner ones were automatically thrown in gear, and the machine again traveled forward. Friction rollers supported the end of the turn-table arm as the weight passed off or on.

The wheel base of the lower carriage was 3 feet 8 inches, and the only caution required was to see that the machine kept square with the track. Owing to the sharpness of the curve, there was considerable noise made in passing around it, but the machine did its work well. The design was elaborated and the machine built by Messrs. Schoener & Allen, of Tamaqua, Pa.

Cable Making at the East River Bridge.

By request of Col. Paine, whose time has been completely taken up by other matters since the cables were completed, I present also the following record of work accomplished in his department:

The last public record was made in the reports for the year 1876, and as these were sent to all the members of the Society, it is deemed sufficient to refer to them for the history of the preparations for cable making.

During the winter of 1876–7 the foot-bridge was completed, the contract made for the cable wire, and all necessary preliminaries settled.

Among these, one of the most difficult was found to be the adjustment of the four wires used as guides in adjusting the cable wires. It was at first thought to be sufficient to fix them by the deflection of the centre span alone; but it was found that the land spans hung at deflections totally different from each other, and, after considerable trouble, it was found to be due to slight differences in diameter and weight of the various lengths of wire.

To overcome this a large number of coils were stretched out, measured and weighed, and enough selected of uniform size and weight to make up the lengths required.

After this the weather had to be watched for periods of perfect calm, when no sun was shining, during which times only adjustments could be made. The whole time thus occupied was about six weeks.

On the land spans the line of reference was a tangent to the curve whose position had been calculated; and on the centre spans it was a level line tangent to the lowest point of the curve. Allowances were made for the temperature ruling at the time.

Another point which was worked up during this winter was the method of joining the coils of wire together. The coupling finally adopted gave from 95 to 98 per cent. of the full strength of the wire, with the coupling ungalvanized; and after galvanizing the joint the *full* strength was developed.

The wire at first specified had a diameter before galvanizing of about 0.167 inches, diameter being Birmingham gauge, No 8, full. The coupling was made from Bessemer steel wire 0.281-inch diameter, and was $1\frac{1}{16}$ inches long. This was drilled longitudinally, and then the hole was

reamed out for about one-fourth of the length in at each end, so as to taper from the full size of the wire at the ends to about the diameter of the bottom of the screw thread at the inner end of the taper. Then one end was tapped with a right handed, and one with a left handed tap. Dies of a similar shape to the coupling were made for cutting the threads on the wire.

At first considerable irregularity in the strength of the joints was observed, and it was found to be due to the dies changing shape in hardening to an amount reaching sometimes $\frac{9}{1000}$ of an inch. This was overcome by making an adjustable die, so as to secure uniformity in size.

The first cable wire was carried across the river May 29th, 1877, and from this time cable making was continuous. At first an unforeseen difficulty was encountered from the unscrewing of the couplings while the wire was in transit. After considerable experimenting a plan was adopted which overcame the trouble perfectly. This was the simple device of clipping the ends of the wires diagonally, so that when the coupling was screwed home they would overlap and effectually prevent the wires from turning separately in the coupling.

Simultaneously with this came the training of the men who adjusted the wires. The adjustment had, of course, to be progressive—first a land span, then the centre span, and finally the opposite land span.

The differences in weight of similar lengths of wire showed itself here often by making one quarter hang high and another low. The adjusters were in such cases instructed to make the differences equal, so as to balance each other, thus securing uniform lengths and a perfect adjustment. Marks were made on the wire with paint as soon as an adjustment was complete at any point, so that slipping could be at once detected.

The first strand was completed and lowered into position and attached to the cable bars on July 14th, 1877. As it would be impossible to *lengthen* a strand, all strands were made by preference a trifle too long, and adjusted to length after lowering. To allow of this the shoes over which the wires pass at either end have a slot through them instead of a round hole, and segments are inserted back of the pin to secure the exact length.

The lowest or *first* strand in each cable was adjusted in the same manner as the guide wires had previously been; and the succeeding ones were adjusted from these by calculating differences in elevation due to

their own particular lengths. The differences in *length* were due to different positions in the saddles, different points of attachment at the cable bars, cradling of the cables, &c., and it will be seen that the process of adjustment was an exceedingly delicate one.

It was usually done very early in the morning to avoid differences in temperature.

When the strands were finally brought together for wrapping, each one came to its place admirably, much to the satisfaction of all concerned.

The experience on the first strands showed that there was no difficulty in getting the requisite quality of wire; and it was then decided that as larger wire could be had which would comply with the specifications, and as its use would facilitate the work, its size should be increased from No. 8 to No. 7 wire, which is about 0.187½ inches diameter.

This gave, instead of 14 feet to the pound, about 11 feet to the pound, and made a material difference in the length to be run out.

The speed of the traveler averaged 5½ feet per second, and as the wire ran out at twice this rate, 11 feet of wire were run out per second by one, or 22 feet when both travelers were working.

In order to keep the strands distinct, and also to prevent chafing, they were, after completion and before lowering, seized throughout their length, at points 2 feet 4 inches apart, by about 5 turns of No. 14 annealed wire. These seizings were removed always in advance of core making or cable wrapping.

After twelve strands of a cable were completed, the central seven (being the ones which were to occupy the centre of the finished cable) were brought together compactly, to form the cable core. This was done by the aid of screw clamps; the outer strands being pounded with wooden mallets so as to distribute the wires uniformly around the central one of all. A fresh seizing was put on the core at short distances as the compressing progressed.

Everything went on well until June 14th, 1878, when the fifteenth strand of the up town cable was in process of lowering. By the unfortunate fouling of a wire rope, causing its rupture, the strand fell, killing two men, and causing a total loss of the strand.

The last wire in the cables was run over October 5th, 1878. The next operation was to draw all the strands in each cable together at each end

to a true cylindrical form. This was done, and heavy clamps put on at 21½ feet from the anchor bars. It must be borne in mind that at the point of joining with the anchor bars the strands spread to a rectangle nearly 5 feet square; hence the necessity for permanent clamps at the points mentioned.

Regular work on cable wrapping began October 25th. The wire used for this purpose was charcoal iron wire No. 10, drawn a little hard and galvanized. As the wrapping was done, every part of the cable was saturated with linseed oil.

The coils of wrapping wire were joined together by a twist splice. The two ends to be joined were tapered for about 4 inches, then twisted together, and the whole swaged. This left but a slight enlargement, which passed readily through the wrapping machine. Every joint was finally galvanized. The operation of cutting the seizings of the core and flatting out the external strands, &c., preceded the final wrapping also—the ends of the seizings being pulled out with pincers and hooks. Clamps were screwed on in advance to bring the cable wires into close contact, and the wrapping wire was put on under considerable tension. It is calculated that the friction between the wires is so great that if cut it would be impossible to pull out 10 feet of any cable wire, as the friction in that length would more than equal its tensile strength.

The speed of wrapping was from 16 to 20 feet of cable per day per gang, 36 feet being an extreme limit.

The work was completed finally on February 17th, 1879, or in about 15 months less time than was thought possible when it began.

During the summer of 1878 the suspender ropes were all cut to length, and sockets attached. As the ropes are all of twisted wires it was necessary (to secure accurate lengths) that they should be measured under strain. Accordingly one socket would be attached, the rope uncoiled and stretched out, and the socket put over a pin; then, by an ingenious parallel motion clamp, made to grip the rope without injuring it, a strain of about 6 tons would be put upon it, and the requisite length marked off. The old method of cutting was by a chisel and sledge, and was very tedious; it always separated the wires, and caused much trouble in inserting them into the socket. To obviate this Mr. Abbott, assistant in charge, designed a circular cutting shears, which, instead of separating, compressed the wires together, and resulted in a saving of an hour on

every socket. It ought here to be said that the clamp mentioned, and also the machine for clipping the ends of the wire diagonally, were designed by Mr. Abbott.

The method of fastening pursued in every case was to let the wires project a little beyond the cone of the socket, then to untwist and separate them as widely as possible; next, to drive in all the large iron pins (with a taper equal to that of the socket, and length a little less) that could be inserted; then to follow these by shorter and smaller pins until it was impossible to drive in any more; the wires were then bent over upon the heads of the pins, and finally all poured full of lead to keep out the weather.

As the *strongest* wires would be those approaching nearest to the minimum of ductility allowed by the specifications, they would frequently break under this bending test, which was much more severe than the specifications required (being almost a right angle, and accompanied by a blow). The number broken reached from one-eighth to one-fourth of all; but as the bending down of the ends was not relied upon for strength, no harm can ensue. The friction of the pins is entirely sufficient to break the rope.*

The cables to the foot-bridge were made of a much harder wire, and even more of them broke in putting on the socket, but no sign of yielding has ever occurred, although they are subjected to about three times the strain, in proportion to their strength, that will ever come upon the suspenders.

The strain put upon each rope, when cut to length, was nearly up to its full working strength, and not a socket yielded in the least. These facts are mentioned to show that with proper care this method of fastening is absolutely secure.

The bands for attaching the suspenders to the cables have all been made, and will probably be put in place during this summer.

I have thus given a brief summary of the leading facts concerning this portion of the work; but it would seem desirable that a statement should be made of some of the results of our experience in the use and testing of steel:

1st. Referring to steel wire, it has been satisfactorily demonstrated

* Tests since made on full length ropes have proved this to be true, and also that the wire, both in ductility and tenacity, was above the requirements of the specifications.

that no satisfactory test of the elastic limit, or amount of stretch, can be made on wire drawn and coiled in the ordinary way, on account of the set induced by coiling.

2d. The elastic limit of straight wire was found always to be more than 50 per cent. of the ultimate strength.

3d. There is no difficulty in getting steel wire that shall lay out straight when loosened from the coil. It simply requires that it be led straight a sufficient distance from the galvanizing trough to be cooled before coiling, and that the coils be not made too small. Our coils were 4½ feet in diameter.

4th. Galvanizing was found to increase the strength of freshly drawn wire *about* 15 per cent. It was a common thing for ungalvanized wire which fell below the required strength to come up to it after a week or two, the gain being nearly 5 per cent. Even galvanized wire would gain in strength slightly by rest. The only explanation of this is the accommodation of strains induced by the drawing. In the case of galvanized wire, however, there may be a remnant of occluded hydrogen, due to the galvanizing process, which is known to have a temporary weakening effect.

5th. Steel wire can be had in quantity of a tensile strength of 160 000 pounds per square inch, with a stretch of 2½ per cent. in breaking in 100 feet lengths; and of 4 per cent. in breaking in 1 foot lengths; and capable of being coiled continuously around a ½-inch bar.

6th. The steel required to give this strength in wire of sizes No. 7 and No. 8 B. W. G., when in sizes such as are required for *ordinary bridge* members, has a strength of only 70 000 pounds to 75 000 pounds per square inch, with an elastic limit of 40 000 pounds, and a stretch of 10 per cent. on full length of bar, or 15 per cent. on samples 1 foot long.

7th. Tests by impact, made by allowing weights to fall lengthwise, of wire having a tensile strength of 3 400 pounds per wire, gave results as follows:

A 100 pound weight falling freely $3\frac{7}{16}$ feet broke a wire 1 foot long. The same weight fell 34 feet to break a wire 100 feet long.

The amount of work done in the first case by the weight was 370 feet pounds; and in the second case 3 400 feet pounds.

8th. A logical deduction from these experiments is that the longer the members in a bridge the *safer* it becomes to use high grade material; and, while it is absolutely safe to use wire such as was used in the cables

of the East River Bridge in members of that length, it would be totally *unsafe* to use anything approaching such material in the trusses of the same.

In making specifications recently for steel for the bridge trusses the requirements as to quality were those mentioned in the sixth head above. Previous to this bids had been asked on the basis of wrought iron, for the reason that only a year ago it was questionable whether proper shapes could be produced in this country in steel. This difficulty having been overcome, and the continued tests of steel by Col. Paine having more fully demonstrated the desirability of using steel, Col. Roebling and the Trustees decided to ask bids anew for an all steel bridge. The field is a new one, and the engineering department has endeavored to make use of the latest knowledge on the subject, and at the same time to be entirely safe.